



# **IMPROVED SIMULATIONS OF PHOTOINJECTORS FOR HIGH-AVERAGE-CURRENT FREE-ELECTRON LASERS**

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**Advanced Accelerator Concepts, 10-15 July, 2006**



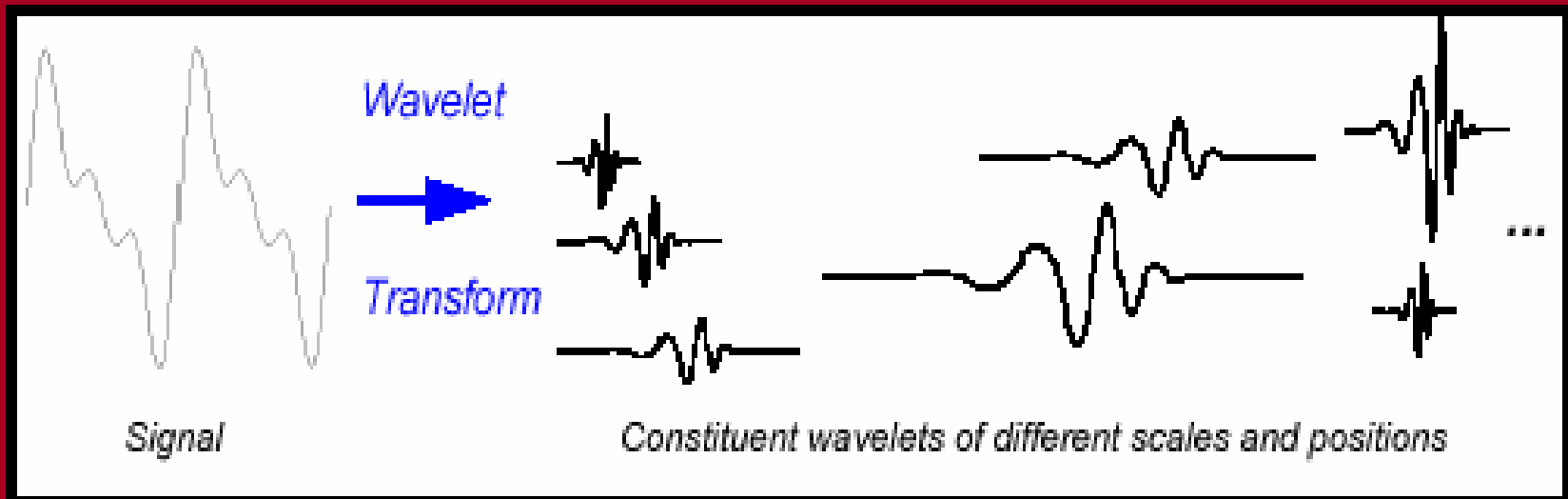
# Outline

- **Advantages of Wavelets**
- **Verification, Validation: Fermilab/NICADD rf photoinjector**
- **Application: AES/JLab dc photoinjector design**
- **Summary**

# What are Wavelets?

In general, they are a family of representations using:

- hierarchical (nested), often orthogonal basis functions
- finite domain (“compact support”)
- fast transforms (faster than FFT!)



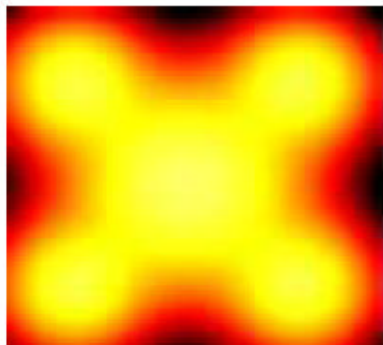
# Wavelet Denoising and Compression

- Whenever discrete signal is known analytically, one can compute signal/noise ( $SNR$ ):  $SNR \propto N_{ppc}^{1/2}$ ,  $N_{ppc} = N/N_{cells}$

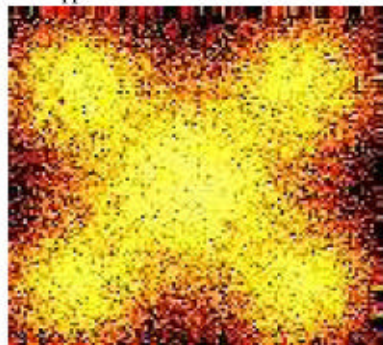
2D superimposed Gaussians on 256×256 grid

COMPACT: only 0.12% of coeffs

ANALYTICAL

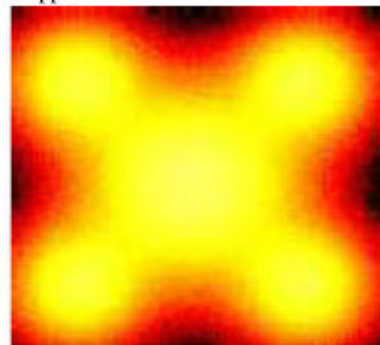


$N_{ppc} = 3$   $SNR = 2.02$



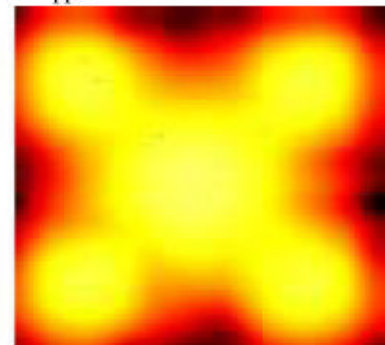
WAVELET THRESHOLDING

$N_{ppc} = 205$   $SNR = 16.89$



DENOISED

$N_{ppc} = 3$   $SNR = 16.83$



- $a$ -fold increase in  $SNR$   $\Leftrightarrow$  equivalent to  $a^2$  more particles!
- Particle distribution is *compactly stored* in wavelet space



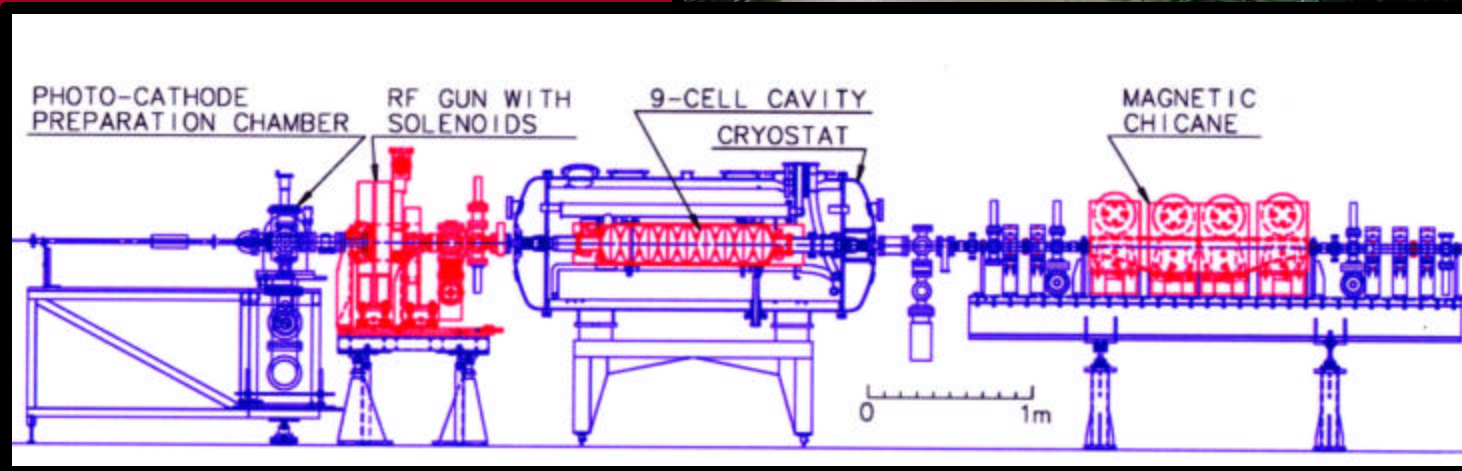
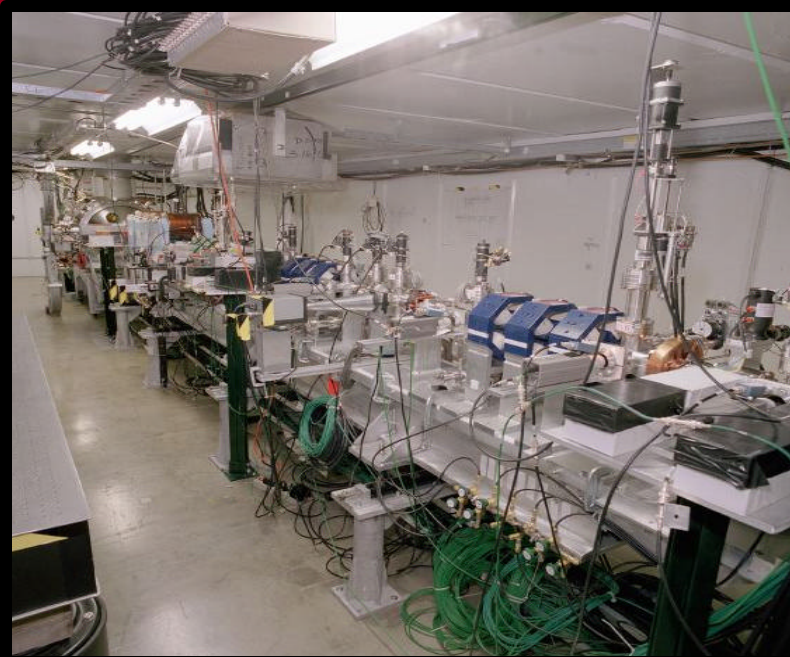
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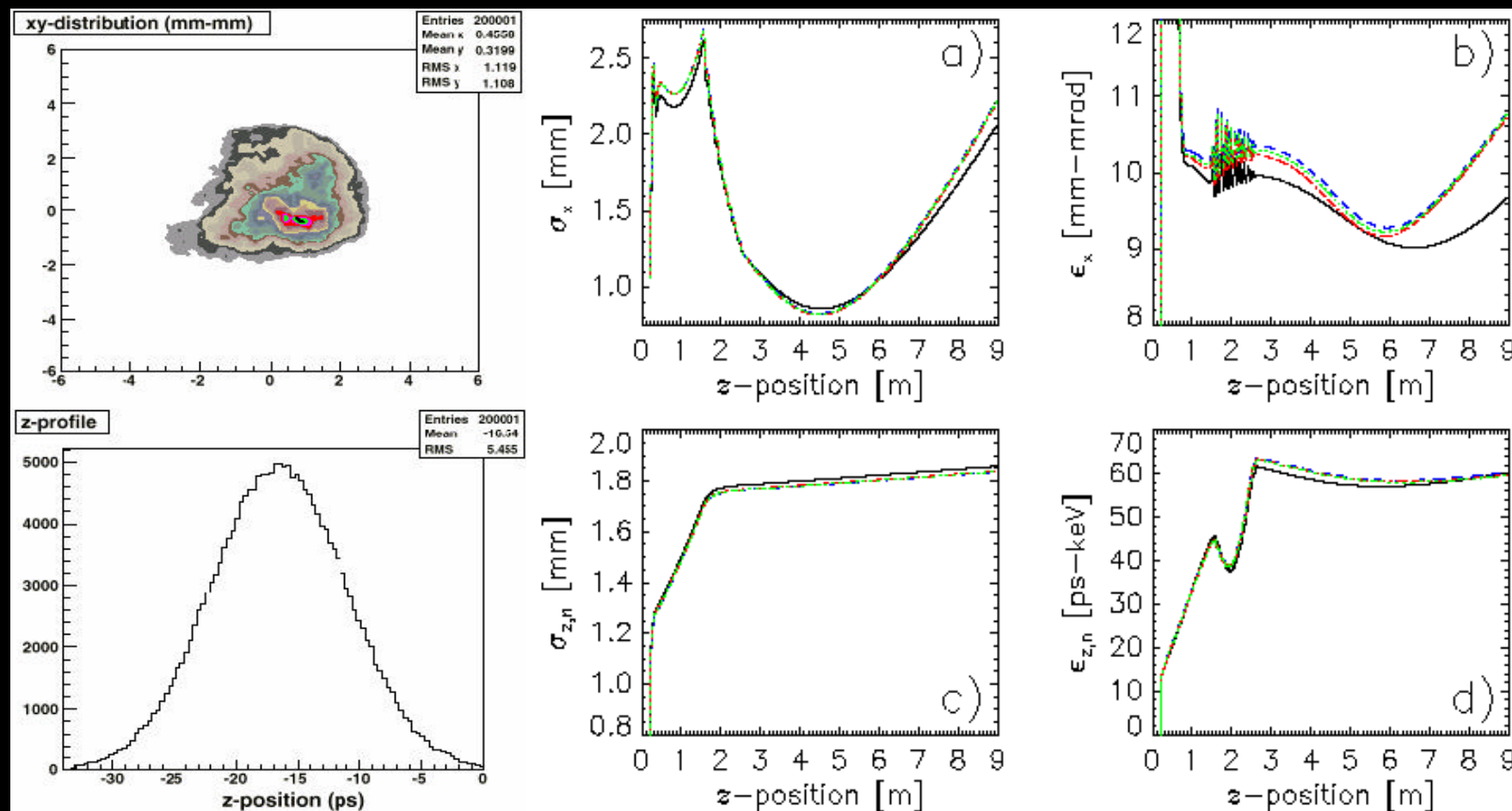
## Fermilab/NICADD Photoinjector Laboratory

- **Electron source at A0**
- **Jointly operated by Fermilab/NICADD**
- **Beam Physics**
- **International Facility**  
(Chicago, Cornell, Georgia, Michigan, NIU, Rochester, UCLA, UIC, Fermilab, DESY, LBL, INFN Milan)





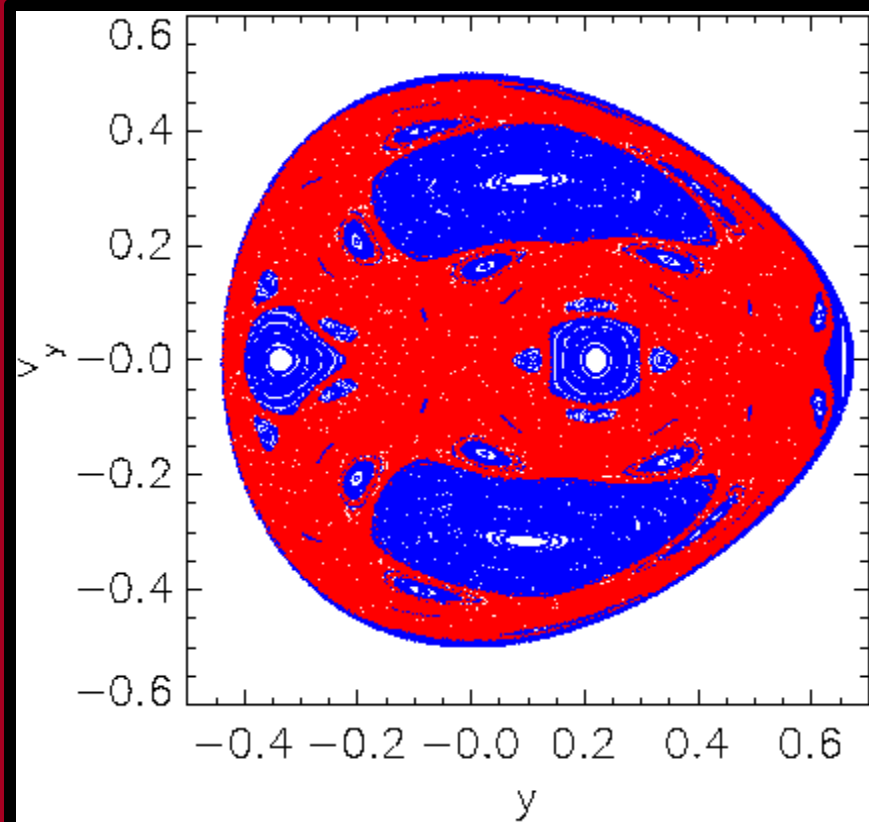
# Fermilab/NICADD Photoinjector Simulations: 1 nC Bunch



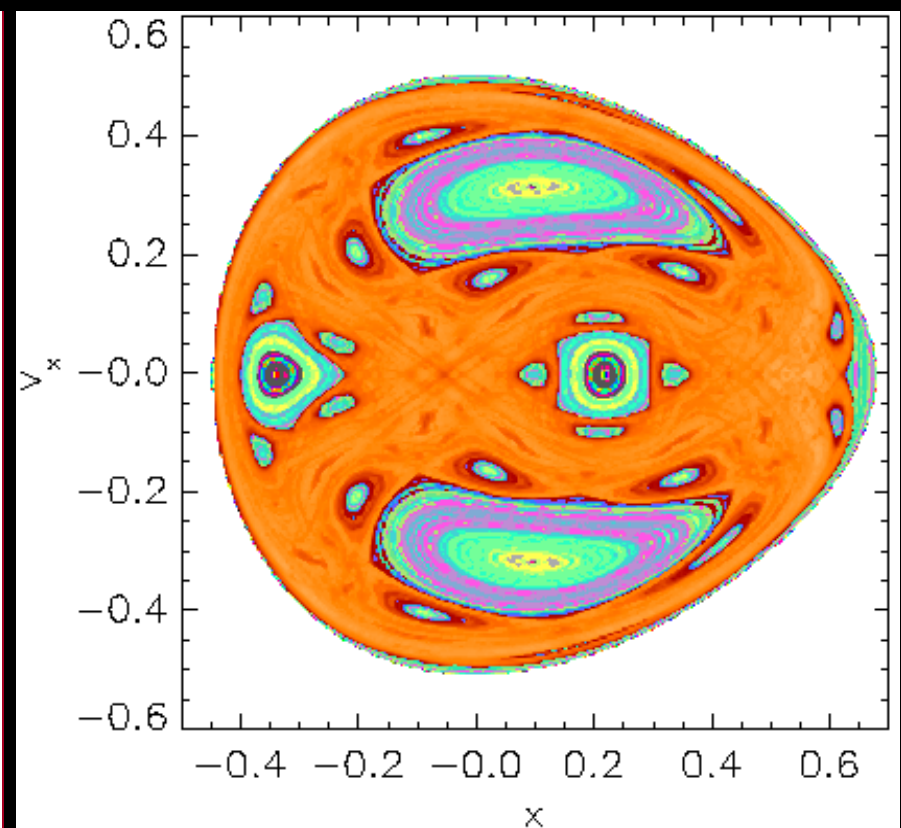
conventional IMPACT-T (—); wavelet IMPACT-T: with (—), without (—) denoising

# Code Diagnostics: Phase-Space Microscope

New tool reveals computed dynamics in *unprecedented detail* !



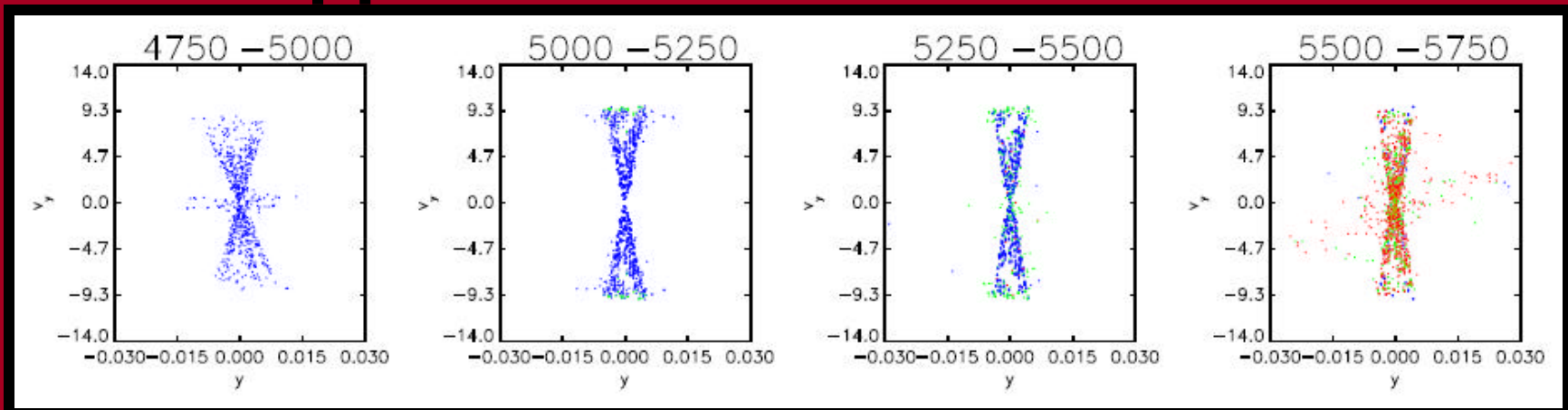
previous state of the art



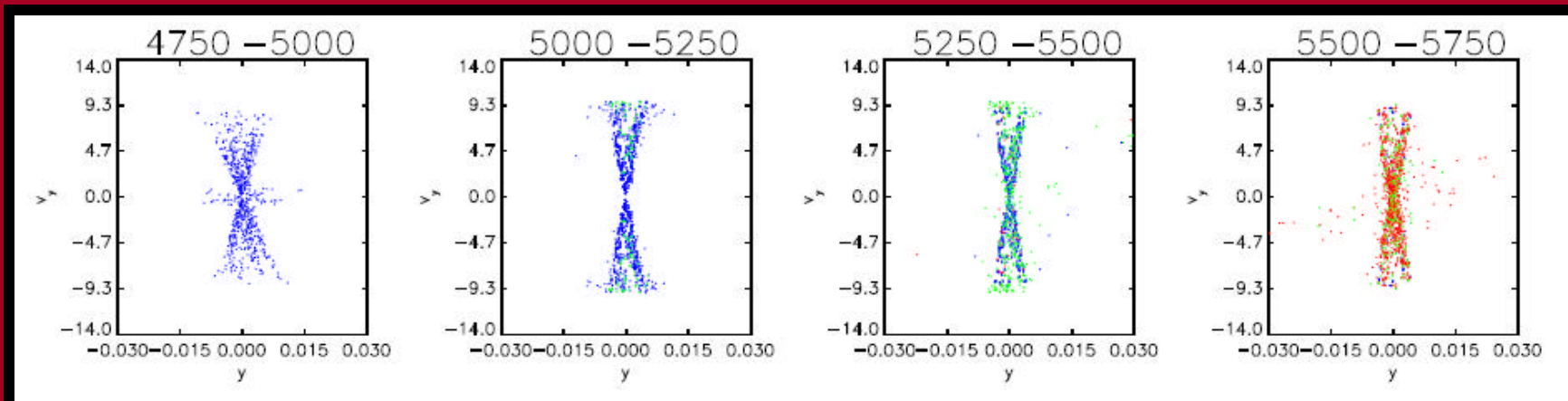
new capability



# Application: Code Verification

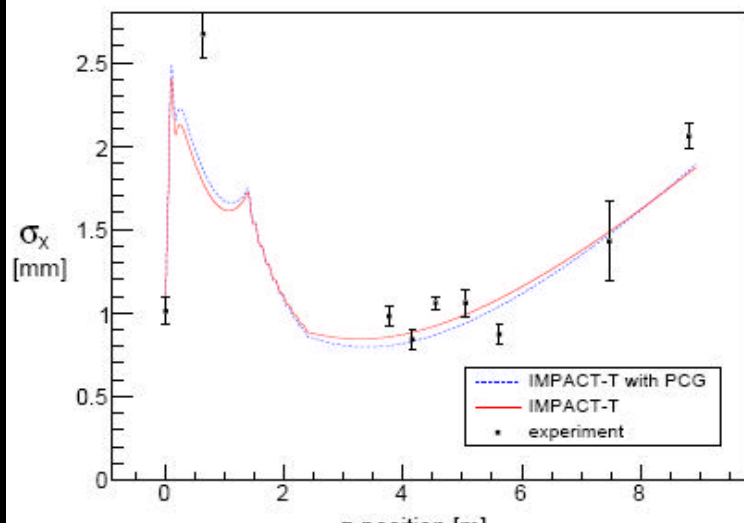


**Simulation with Green function + FFT Poisson solver**

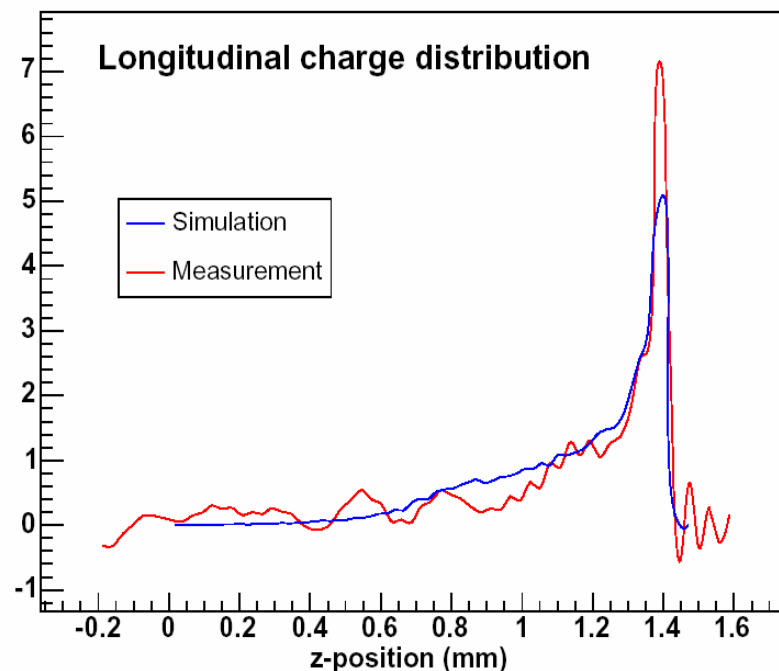
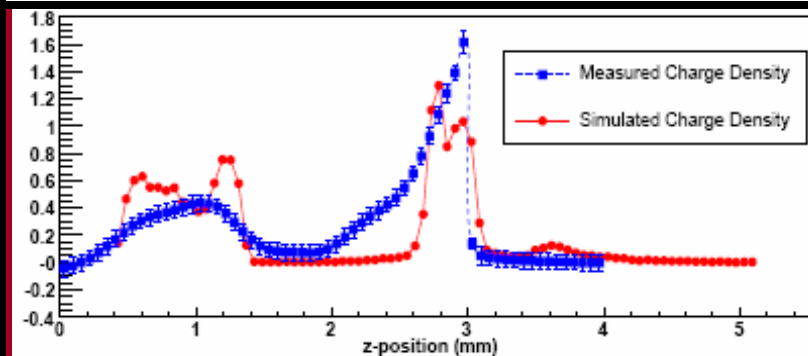


**Simulation with wavelet-based Poisson solver**

# Code Validation: Fermilab/NICADD Photoinjector Data



Transverse rms beam size of 1 nC bunches:  
measured ( $\bullet$ ), conventional IMPACT-T (—),  
Wavelet IMPACT-T (---).



Longitudinal density profile of compressed  
3 nC bunches: **measured** (red) vs. **PARMELA**  
with 20,000 particles (blue).

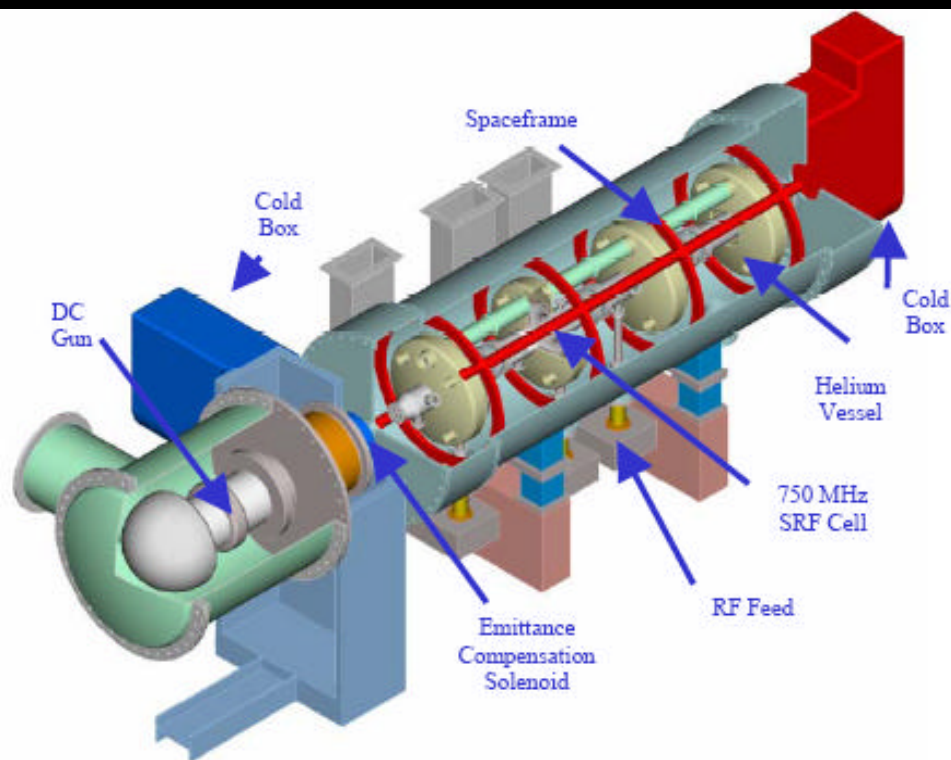
Longitudinal density profile of compressed  
double-bunch (0.5 nC ea.) configuration:  
measured, conventional IMPACT-T.



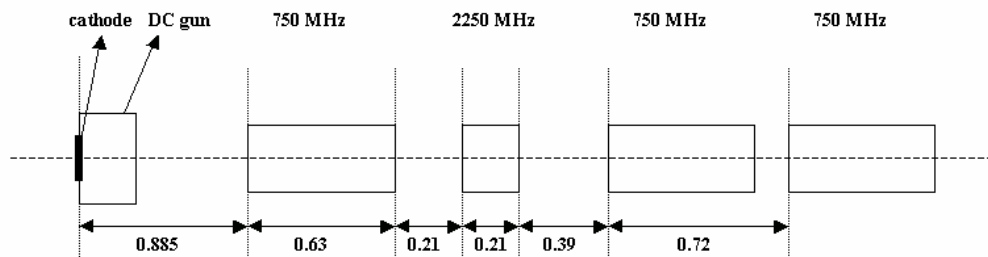
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# The AES/JLab Photoinjector



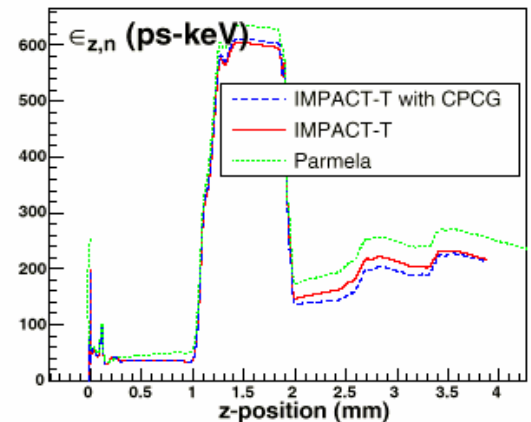
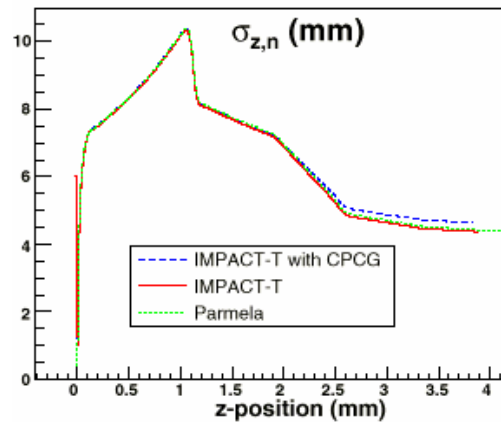
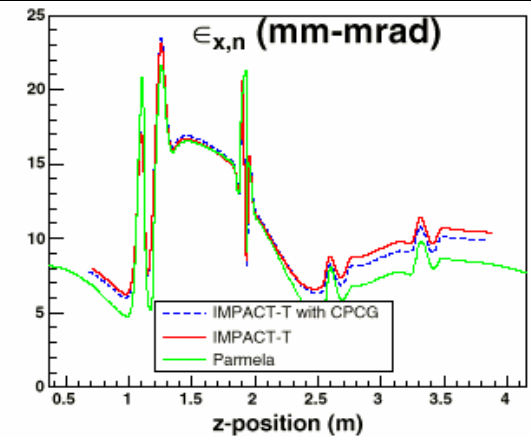
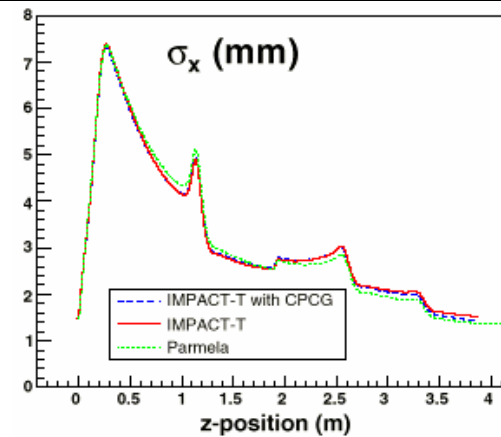
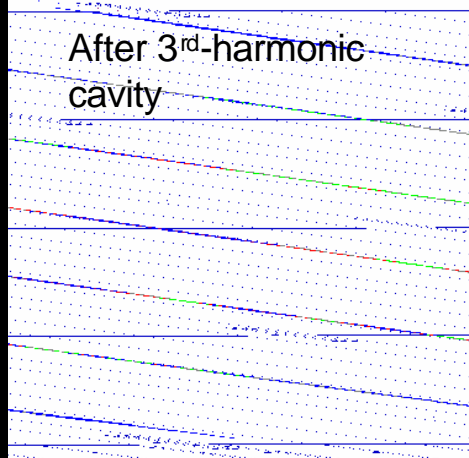
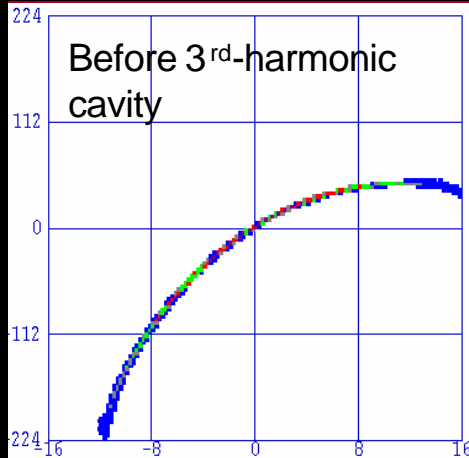
Original 0.1 A design  
(0.133 nC bunches)



Present ~1 A layout  
(1 nC bunches)

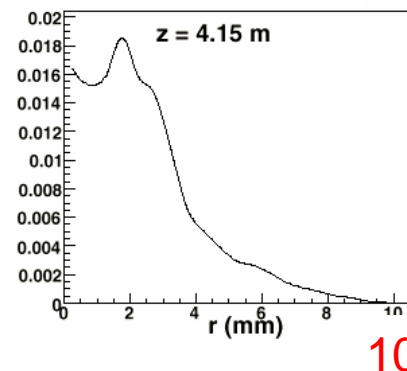
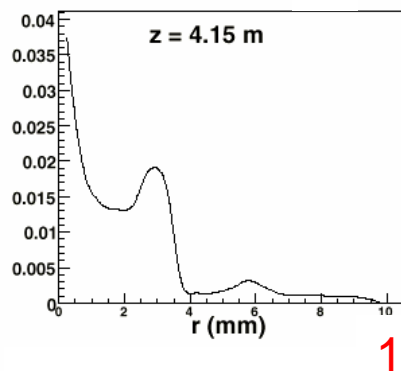
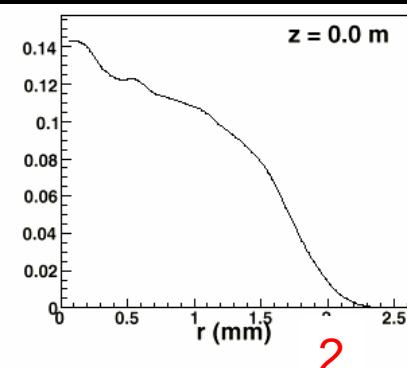
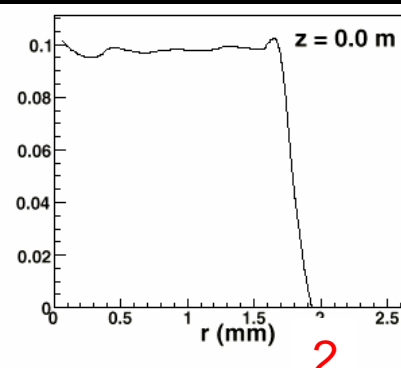
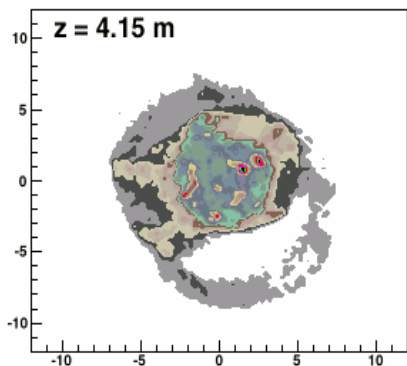
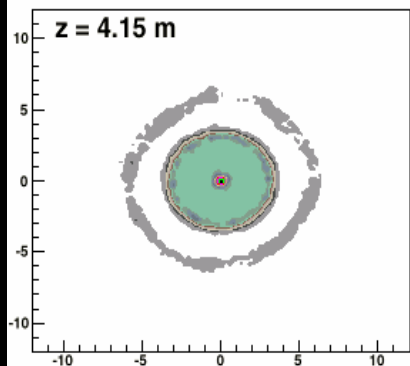
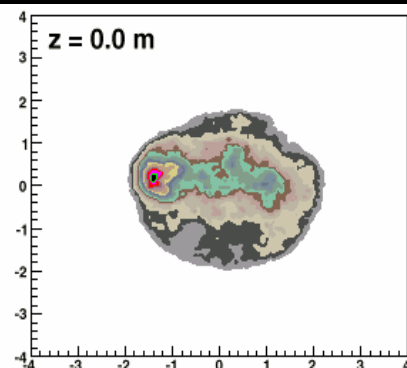
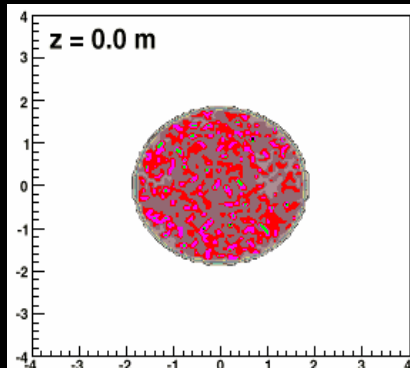


# AES/JLab 1 A Photoinjector Simulations: 1 nC Bunches



conventional IMPACT-T (—); wavelet IMPACT-T(---), PARMELA (—)

# AES/JLab 1 A Photoinjector Simulations: Halo!



Transverse spots at cathode (top)  
and exit (bottom)

Density profiles at cathode (top)  
and exit (bottom)



# Summary

## Accomplishments:

- **Built & implemented wavelet-based Poisson solver**
- **Built new tool for dissecting chaos in orbits**
- **Measured transverse & longitudinal moments of Fermilab/NICADD photoinjector beam**
- **Verified (vs. other codes) & validated (vs. data) the new wavelet-based code**
- **Applied the new code to the AES/JLab photoinjector design (result: halo!, plus output energy is 'low')**

## To Do:

- **Optimize & parallelize the new wavelet-based code**
- **Optimize AES/JLab photoinjector settings to reduce halo**